LANSCE
Los Alamos Neutron Science Center

Research Proposal for the use of Neutron Science Facilities

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Proposal Number: 20111523
Submission Number: S1550
Date Received: 03/09/11

Program Advisory Subcommittee: Basic Nuclear/Particle Physics
Focus Area:

Flight Path/Instrument: Target 2 / Blue Room
Dates Desired: 2 days in August and 2 days in De
Estimated Beam Time (days): 4
Impossible Dates:
Days Recommended: 0

TITLE
Radiation Hard Technologies for the Super Large Hadron Collider

☒ Continuation of Proposal #: 20101569
☐ Ph.D Thesis for:

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RESEARCH AREA

- ☐ Biological and Life Science
- ☐ Chemistry
- ☐ National Security
- ☐ Earth Sciences
- ☐ Engineering
- ☐ Environmental Sciences
- ☐ Nuc. Physics/chemistry
- ☐ Astrophysics
- ☐ Few Body Physics
- ☒ Fund. Physics
- ☒ Elec. Device Testing
- ☐ Dosimetry/Med/Bio
- ☐ Earth/Space Sciences
- ☒ Materials Properties/Test
- ☐ Other:
- ☐ Mat'l Science (incl Cond Matter)
- ☐ Medical Applications
- ☐ Nuclear Physics
- ☐ Polymers
- ☐ Physics (Excl Condensed Matter)
- ☒ Instrument Development
- ☐ Neutron Physics
- ☐ Fission
- ☐ Reactions
- ☐ Spectroscopy
- ☐ Nuc. Accel. Reactor Eng.
- ☐ Def. Science/Weapons Physics
- ☐ Radiography
- ☐ Threat Reduction/Homeland Sec.
- ☐ Other:

FUNDING AGENCY

- ☐ DOE/BES
- ☐ DOE/OBER
- ☐ DOE/NNSA
- ☐ DOE/NE
- ☐ DOE/SC
- ☒ DOE/Other

DOE/OHEP

- ☐ DOD
- ☐ NSF
- ☐ Industry
- ☐ NASA
- ☐ NIH
- ☐ Foreign:
- ☐ Other US Gov't:
- ☐ Other:

PUBLICATIONS

Publications:

"Powering of Future HEP Detectors in 4T & High Radiation," S. Dhawan, TRIUMF Technical Seminar, August 2010.

"Power Converters: why the commercial world is betting on gallium nitride to replace silicon," S. Dhawan, CERN PH-ESE Electronics Seminar.

"Planar Pixel Activities in Santa Cruz," V. Fadeyev, ATLAS PPS Project Meeting, November 2009.

"Planar Pixel Activities in Santa Cruz," V. Fadeyev, ATLAS PPS Project Meeting, April 2010.

"Annealing Effects on Depletion Voltage and Capacitance of Float Zone and Magnetic Czochralski Silicon Diodes After 800 MeV Proton Exposure," J. Metcalfe et al., IEEE Nuclear Science Symposium Conference Record, November 2010.

"Silicon Detectors for the sLHC," J. Metcalfe et al., Nucl. Phys. B. Proc. Supp., submitted July 2010.

"Temperature Effects on the Operational Characteristics of CVD Diamond Sensors," R. Wang, IEEE NSS-MIC, November 2010.

Abstract: S1550_lansce-propo.pdf

By electronic submission, the Principal Investigator certifies that this information is correct to the best of their knowledge.

Safety and Feasibility Review ***(to be completed by LANSCE Instrument Scientist/Responsible)***

☐ **No further safety review required** ☐ **To be reviewed by Experiment Safety Committee**

☐ **Approved by Experiment Safety Committee, Date:**

Recommended # of days:	**Change PAC Subcommittee and/or Focus Area to:**	**Change Instrument to:**

Comments for PAC to consider:

Instrument scientist signature: **Date:**

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Radiation-hard Technologies for the Super Large Hadron Collider

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Abstract

The Large Hadron Collider (LHC) at CERN will be upgraded (to "Super-LHC", SHLC) in the latter part of the decade to provide proton-proton collisions at 14 TeV and luminosity 10^{35} cm^{-2} s^{-1}. Additionally, over the next 2 years, the existing LHC detectors will be modified (for example, the ATLAS "Insertable B-Layer Upgrade") to maintain their efficiency in the high radiation field. Research is underway to develop technologies for detectors to record what this collider will reveal. Discoveries at the LHC and SLHC are expected to shed light on many fundamental questions including the origin of mass, the unification of the fundamental forces, the existence of extra dimensions, sources of symmetry violation, and the nature of dark matter and dark energy. The high flux of particles produced by the collisions will damage detectors not implemented with radiation hard technologies. We, members of the ATLAS, CMS, RD50, and RD42 Collaborations of the LHC, are presently developing radiation hard technologies for use in the upgraded detectors. Charged hadrons are the main source of radiation damage that these devices will incur. We propose to qualify the front-end integrated circuit for the ATLAS Pixel Detector upgrade; diamond sensors and modules for vertexing and luminosity monitoring; 3D silicon sensors assembled with amplifier chips; planar *p*-type silicon pixel sensors with the "slim edge" design; GaN FET's needed for a new power supply concept, and several epoxies need for building carbon composite mechanical structures to which the collider detector elements are attached. The required proton fluence for the proposed experiment is 10^{16} p/cm^2. We would like to request sufficient time in the 800 MeV line at LANSCE to have two irradiations to this fluence, if possible one in August and the second in December.

1. Motivation

1.1 Introduction

The Large Hadron Collider is scheduled for a luminosity upgrade, SLHC, in the latter part of the present decade. The two multi-purpose experiments, ATLAS and CMS, have created working groups to plan the necessary detector upgrades. Furthermore, the CERN RD50 Collaboration[1] was founded in 2001 to develop semiconductor tracking detectors for the upgraded experiments and the CERN RD42 Collaboration[2] was approved in 1994 to develop diamond tracking detectors for high luminosity applications.

The Super LHC upgrade will be a challenge for data handling and triggering. It will require tracking detectors which can survive extremely high particle fluences. Most of the damage in the tracking layers, which will be equipped with pixel and strip detectors, will be caused by charged hadrons. We propose to measure the radiation damage in components of the tracking system at 4 different proton fluences: $4*10^{14}$, $1*10^{15}$, $4*10^{15}$, and $1*10^{16}$ p/cm^2. This study will lead to a better understanding of the underlying damaging mechanisms and the operational possibilities, and a scaling to SLHC-relevant fluences will become possible. We are requesting two cycles of irradiation; conclusions drawn after the first run will guide design revisions which can then be tested in the second run.

1.2 Expected Fluences

Evaluations of the radiation field by the ATLAS Radiation Task Force [3] have generated predictions of the expected fluences in the ATLAS Upgrade tracker in terms of 1 MeV neutron equivalents [4]. Figure 1 shows the predicted fluences for an integrated luminosity of 3000 fb^{-1}. In addition, an engineering margin of a factor of 2 is assumed. The locations of tracking detectors in an ATLAS "strawman layout" are indicated with 4 pixel layers, 3 "short strips" layers and 2 conventional long strip layers. The neutron equivalent fluences were generated by multiplying the calculated particle fluences with a relative damage factor, which is 0.62 for high energy protons and close to unity for protons in the few hundred MeV range [4]. This factor is based on the Non-ionizing Energy Loss hypothesis (NIEL) described in detail in Ref. [4].

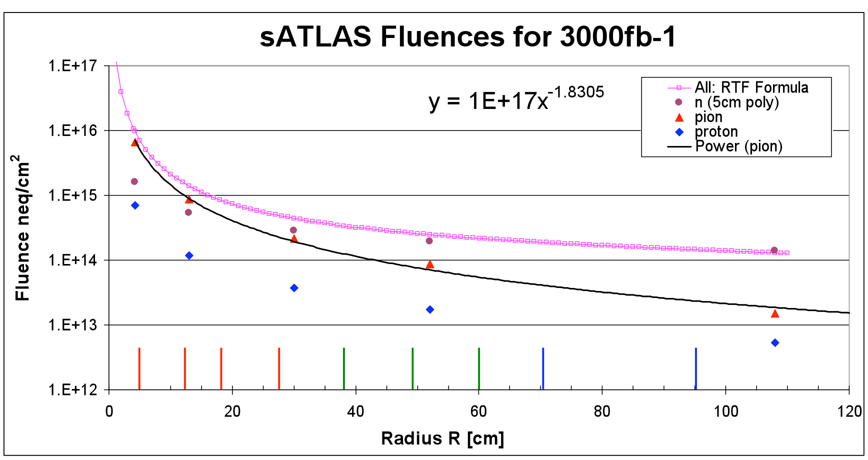

Fig. 1. Fluence in the ATLAS upgrade tracker in 1 MeV neutron equivalent as a function of radius[2].

1.3 Devices under Study

1.3.1 ATLAS Pixel Front End Chip

The ATLAS pixel front-end integrated circuit, FE-I4B, has been developed [5] in 130 nm technology. The new digital architecture necessitated by the increased luminosity is based on local pixel logic, local pixel data storage, and a mechanism to drain triggered hits from the double column. The new front-end is made of smaller pixels, an improved active over inactive area ratio, and a new analog pixel chain tuned for low power and new detector input capacitance. The present ATLAS pixel architecture is based on pixel hit transfer to End-of-Column buffers located in the periphery; the data recorded in these buffers waits until ATLAS Level 1 Trigger latency, either for confirmation and readout or for erasure. This transfer process is time-consuming, and the pixel that fires remains inactive until the data shipment to the next available End of Column cell is finished. This transfer starts to be highly inefficient at a few times the LHC design full luminosity, resulting in unacceptable data losses at SLHC luminosity. Additionally the pixel hit rate is greatest at the innermost layers, translating to the most extreme requirements on, for example, the Insertable B Layer. The new pixel modules will be based on a reduced number of larger chips relative to the present design. Additionally each front end will handle functions that were previously included in the Module Control Chip. The implementation of local buffers is rendered possible by the smaller feature size of 130 nm technology. The devices to be tested are the 2cm x 2cm final chips. This design has been evolved with input from LANSCE irradiations of engineering-run devices in 2009 and 2010. Limited single event upset data are required along with general radiation hardness qualification.

A new FE design intended for future pixel detectors is now in the prototype stage with 65 nm feature size. We would like to include a few of these chips, of size 3mm x 4mm as well. A total dose of 1000 MRad would be ideal for this; we propose to irradiate each device to 500 MRad in August and another 500 MRad in December.

1.3.2 Planar p-type Silicon Sensors

As defects induced by radiation in silicon are dominantly deep acceptor-like traps, type inversion is not expected in n-on-p silicon detectors. Thus, p-type detectors have the critical advantage over traditional p-on-n devices that the high electric field region is always at the readout electrode: the detector can be operated under-depleted, i.e. the bias voltage does not have to exceed the depletion voltage for efficient charge collection. We are developing a "slim edge" sensor design with the goal of increasing active area by removing inactive device periphery and post-processing. Initial tests of slim edges in n-type sensors have proved promising, however the transfer of this idea to p-type requires new technology. We have fabricated a number of n-on-p detectors through various foundries (HPK, CiS, and Micron) and are prepared to compare their operation. This study follows upon our LANSCE activities in 2008, '09, and '10 with the important development that pixels, rather than strips, will be under study. These have significant differences in guard ring layout and manufacturing techniques that can influence radiation hardness. We propose to irradiate 10 devices of dimensions 1 cm x 1 cm x 300 microns.

1.3.3 Diamond Sensors and Modules

Diamond, grown in a chemical vapor deposition process, is known to be radiation hard up to fluences of $10^{15}/cm^2$ 24-GeV protons. The signal response to a minimum ionizing particle in the best diamond samples is 9000 electron-hole pairs. A most probable signal-to-noise ratio of 7:1 has been obtained with fast readout (SCT 128/DMILL, 25 ns signal peaking time) electronics. A spatial resolution of 15 microns has been obtained in a recent beam test at CERN. We will irradiate six single crystal and two polycrystalline diamonds to characterize the radiation tolerance of the material. This is a milestone development since our 2010 irradiation of polycrystalline diamond. Single crystal has been shown to provide charge collection distances on the order of 250 microns, comparable to the dimension of the device. It is important to check that these single crystal devices have the same damage constant as the polycrystalline ones do. The single crystal devices have dimension 4.5 mm x 4.5 mm; the poly, dimension 1 cm^2.

1.3.4 GaN FETs for Power Supply Buck Converters

Power electronics have become a focus of intense R&D in industry. The industrial approach has featured the distribution of voltages higher than are required by the electronics. The voltage is stepped down at the point-of-load to provide the low voltages and high currents required by the electronics. The devices that perform these conversions, called DC-DC converters, use either magnetics in the form of inductors or transformers, or capacitors. Efficiency favors magnetic converters in high ratios of input to output voltage and thus magnetic converters are the focus of our research. The simplest magnetic topology for the DC-DC converter is called a Buck Regulator. High Energy Physics can benefit from the small size, high efficiency, and high frequency of these devices if they can meet the requirements of radiation resistance and operation in high (>1 Tesla) magnetic fields. The latter requirement precludes the use of ferrites and drives the need for high frequency operation.

Gallium Nitride material has been used in a HEMT (high electron mobility transistor) structure for which unusually high electron mobility has been measured. Recently GaN on silicon has become available for power converters. These can operate at high input/output ratios, thus reducing power supply input currents. We are studying the application of these to the LHC and International Linear Collider environments, where they outperform silicon devices in high frequency operation, low resistance, and 10 times higher breakdown voltage. Additionally GaN devices can be fabricated using existing silicon infrastructure. This test requires a fluence of 10^{15} p/cm^2.

1.3.5 3D Silicon Sensors

A disadvantage of planar geometry is the link between wafer thickness and electrode separation. For a 300µm wafer, this distance can lead to extremely high depletion voltages in irradiated sensors. The 3D geometry solves this problem by orienting the p^+ and n^+ electrodes through the silicon bulk, perpendicular to the silicon wafer surface. Since the electric field is parallel (rather than orthogonal) to the detector surface, the charge collection distance can be several times shorter, the collection time considerably faster, and the voltage needed to extend the electric field throughout the volume between the electrodes (full depletion) an order of magnitude smaller, for 300 µm thick silicon. We will irradiate assemblies of 3D sensors bump bonded to FE-I4 chips.

1.3.6 Mechanical Materials

Precision tracking of particles in high energy physics experiments requires minimization of mass, without compromise of rigidity, of all inactive detector elements through which the tracks pass. The ATLAS tracker, like most contemporary devices, uses carbon composite for this purpose. We propose to test several epoxies as well as elastic PEEK polymer mounting brackets for upgrades to the tracker barrel. This study requires a fluence of 10^{16} p/cm^2.

2. Required Fluences

An irradiation with fluences of between $4*10^{14}$ p/cm^2 and $1*10^{16}$ p/cm^2 in 4 steps will cover the fluences expected for all layers in the upgraded tracker systems. No special cooling or gas environment is required. This radiation program is supported by RD50 (48 institutions) and RD42 (14 institutions) as well as by the ATLAS and CMS collaborations.

3. Hazardous Equipment and Sample Material

The samples and the setup will be activated during the experiment. The samples will have very little mass (a few grams) and contain mainly G-10, silicon, and carbon, which do not have long-lived isotopes. The dosimetry should be done via Al foils. We may also mount PIN dosimetry diodes and thermal sensors. As they are of very low mass, they will represent only a small activation.

References

[1] CERN-RD50, "Radiation hard semiconductor devices for very high luminosity colliders," http://www.cern.ch/rd50/.

[2] CERN-RD42, "Development of diamond tracking detectors for high luminosity experiments at the LHC," http://greybook.cern.ch/programmes/experiments/RD42.html.

[3] Ian Dawson et al, http://dawson.web.cern.ch/dawson/fluka/SLHC/slhc.html.

[4] ROSE Collaboration, tabulated by G. Lindstrom, http://sesam.desy.de/members/gunnar/Si-dfuncs.html.

[5] M. Barbero et al., "A New ATLAS Front-End IC for Upgraded LHC Luminosity," Nucl. Instr. and Meth. A 604, Issues 1-2, 397 (2009); M. Karagounis et al., "Development of the ATLAS FE-I4 Pixel Readout IC for b-Layer Upgrade and Super-LHC," Proc. TWEPP 2008, Naxos, Greece [online].